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NARROW-BAND F.M. SYSTEM FOR TELEVISION LINKS: a feasibility study

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Summary

The use of f.m. television links at u.h.f. (Band V) depends, at present, upon the availability of a number of adjacent 8 MHz broadcast television channels to accommodate the 16 MHz bandwidth occupied by the transmitted signal.

Because of the expansion of the u.h.f. transmitter network, fewer spare sets of contiguous channels are expected to be available. To overcome this difficulty, it was proposed that the f.m. television signal could be modified to work within a bandwidth of only 8 MHz. To evaluate the proposal, an experimental narrow-bandwidth f.m. system was constructed.

It was found that f.m. television signals could indeed be transmitted successfully in a nominal bandwidth of 8 MHz, instead of the nominal 16 MHz used at present. As a consequence of the bandwidth reduction, both linearity and signal-to-noise ratio were slightly impaired, nevertheless it is thought that a link of this kind should be advantageous under certain conditions.

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1. Introduction

The f.m. television links used for outside broadcasts at present operate at s.h.f. for point-to-point use, and at u.h.f. Band V for point-to-point or mobile use. The Band V links need spectrum space in which to work, and it is becoming increasingly difficult to find sufficient space at some link sites because of interference from the expaning u.h.f. transmitter network and the corresponding risk of interference to domestic reception of u.h.f. broadcasts from the link. Some means of carrying the television signal in a reduced bandwidth would therefore be very useful, hopefully leading to an increase in the number of sites where links may be used in the future.

The purpose of the work described in this Report was to investigate the feasibility of transmitting an f.m. television signal with a vestigial sideband spectrum in a bandwidth of only 8 MHz, instead of the 16 MHz required for the present double sideband system, and to identify any additional system requirements that might arise as a consequence of this bandwidth reduction.

Three further Reports[2–4] will consider the effect of narrow band operation on interference between f.m. links and a.m. broadcast signals, and the susceptibility of d.s.b. and v.s.b. signals to multipath conditions.*

A theoretical appraisal was made of several possible spectrum-shaping schemes, and the conclusions were verified in some preliminary experiments, before arriving at the spectrum shape described below. A system was then evolved by measuring the impairments introduced and minimising these by the various means to be described.

2. Theoretical considerations

2.1 Description of the basic spectrum

Fig. 1 shows the spectrum of a 70 MHz carrier, frequency-modulated by a standard-level a.c.-coupled "non-linearity test" waveform. The deviation sensitivity is 4 MHz/volt after CCIR 625 line pre-emphasis. The test waveform used (shown later in Fig. 8) consists of a "staircase" on each line of the television video signal with a sine-wave at colour subcarrier frequency superimposed on each of the six steps of the staircase.

It can be seen from Fig. 1 that the f.m. spectrum consists of a central group of components, carrying mainly

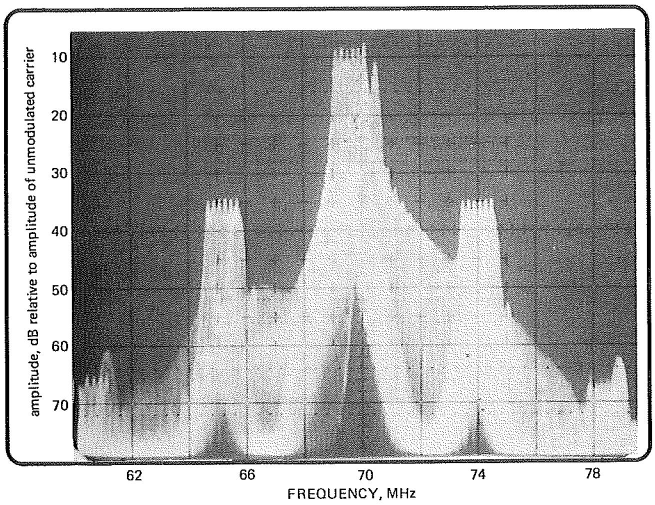


Fig. 1 - Spectrum of the f.m. television signal when the modulation is a staircase waveform (with colour subcarrier).

low-frequency picture information, and two asymmetrical groups of components spaced at ±4.43 MHz from the carrier-rest frequency (70 MHz) carrying predominantly high-frequency and colour information. Low-frequency components in the modulation waveform have a large modulation index, β (the ratio of peak frequency-deviation to modulation-frequency), and therefore produce many closely-spaced sidebands at the centre of the f.m. spectrum, whereas high-frequency components have a low modulation index and produce two groups of first-order sidebands at the modulating frequency from the carrier rest frequency; the higher-order sidebands are of relatively low level. Because the higher-frequency components of the modulating signal produce sidebands above and below the carrier rest frequency, it would appear that a saving in band-width could be effected by eliminating one set of the sidebands.

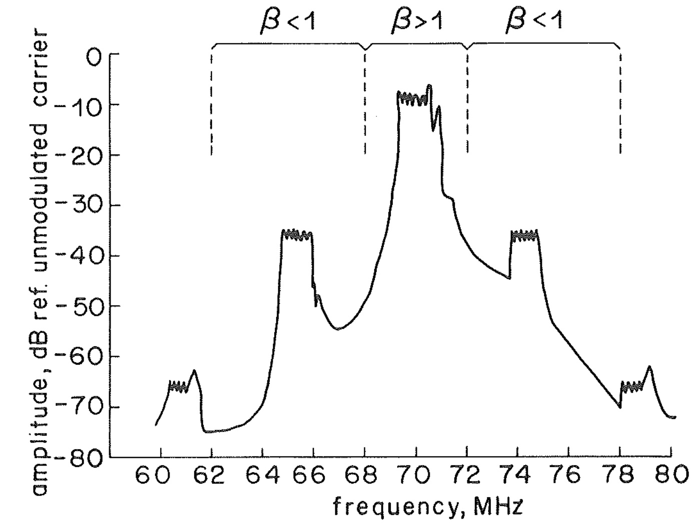


Fig. 2 - Sketch of the f.m. spectrum of Fig. 1 showing the division into three parts.

* It should be pointed out here, that as a result of the work described in Reference 4, it was concluded that, with the system of Band V broadcast channel allocations which exists in the U.K., not enough new link sites are made available to justify the extra expense of the v.s.b. system described in this report. In a different system of channel allocations, however, a v.s.b. system of this type could significantly increase numbers of available link sites.

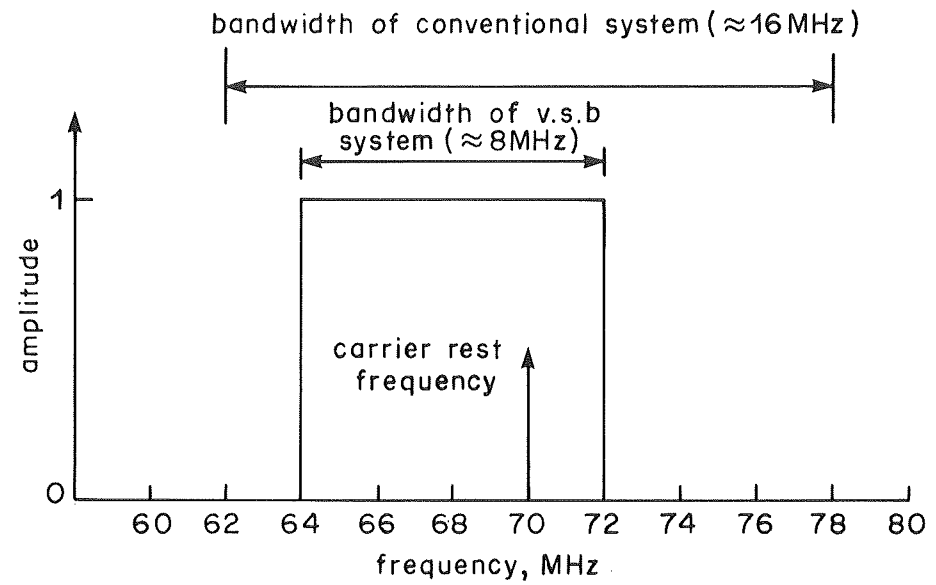
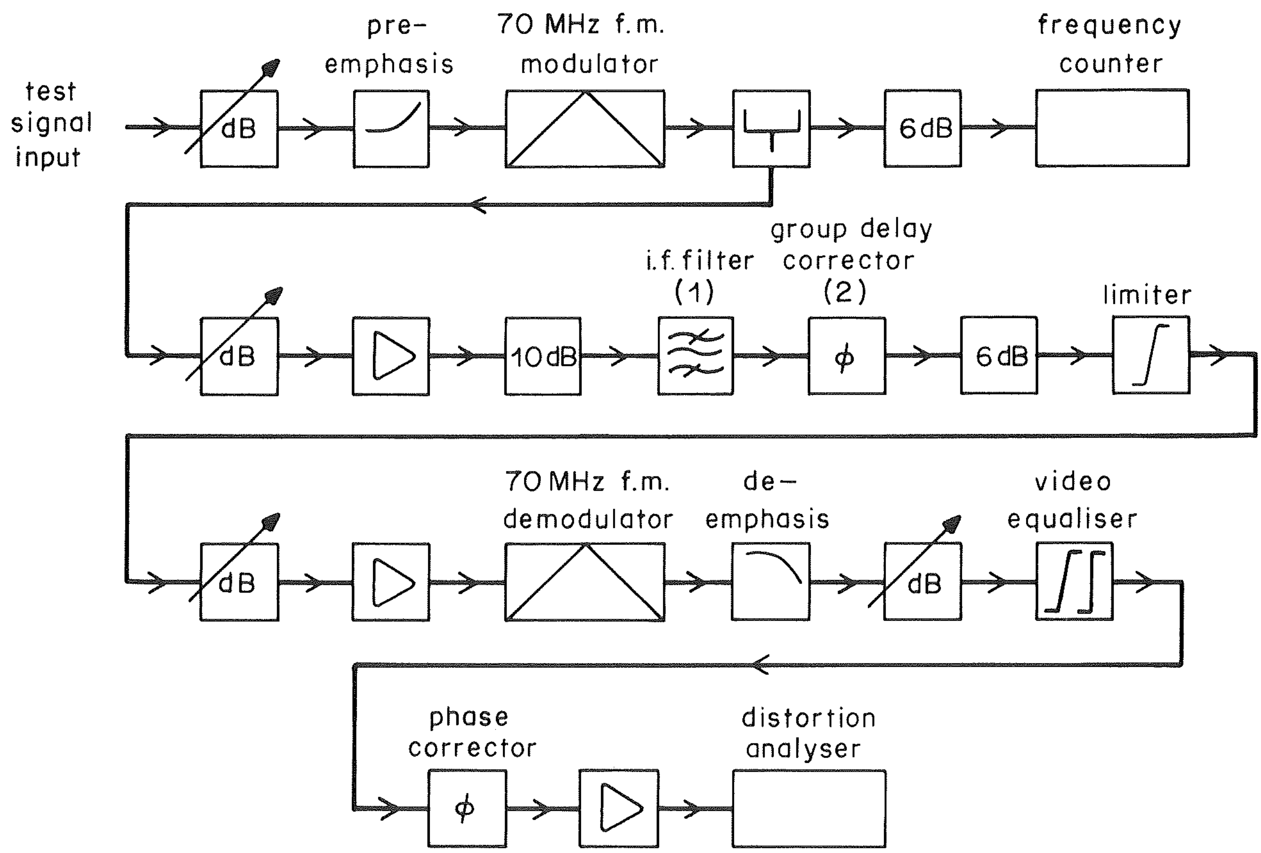


Fig. 3 - Idealised frequency characteristic of the i.f. filter.



(1) 64–72 MHz b.p.f. for v.s.b link
62–78 MHz b.p.f. for d.s.b link

(2) Not used for d.s.b. link

Fig. 4 - Experimental Arrangement

2.2 Spectrum shaping

The three main groups of spectral components produced by the non-linearity test signal are further identified in Fig. 2. This shows one group centred around the carrier rest frequency and extending over 4 MHz (the peak-to-peak deviation); the two other groups of spectral components are located one on each side. A television picture signal will, in general, contain a continuum of frequencies, and under these conditions the sideband structure is not readily divided into such well defined-groups.

A filter which confines the spectrum to within the frequency-range (of 4 MHz) through which the carrier is deviated will introduce severe non-linear distortion of the modulation. This is because a modification of the relative amplitudes of the sidebands in this frequency range by such a filter causes the deviation sensitivity of the system to vary with the instantaneous level of the low-frequency (luminance) information in the modulating video signal; thus non-linear distortion results.

A filter with an asymmetrical passband — passing all the inner sidebands and the outer sidebands on one side of the carrier — will produce what can be regarded as a vestigial sideband (v.s.b.) signal. If the spectrum is shaped in this way, the effect is to reduce the deviation for the higher video frequencies. The change in deviation which results in this case is much less dependent upon levels in the modulating signal, and the distortion introduced is principally linear, affecting the amplitude/frequency response of the system. Non-linear distortion does occur in the part of the spectrum near the skirts of the VSB filter, but this is not important because the energy in this region is low. This is dealt with in greater detail in the Appendix.

It was decided, to employ a v.s.b. filter with a characteristic approximating to the ideal rectangular shape shown in Fig. 3, and to correct for the resultant linear distortion of the video signal using an equaliser. It was decided that the upper portion of the spectrum should be removed because the modulation polarity was such that the synchronising pulses caused deviation towards the higher frequencies; it was thought that any non-linearity introduced by filter group-delay at the pass-band edge would be less significant if only the synchronising pulses were affected. A further 2 MHz was removed from the lower end of the spectrum to give a channel width of 8 MHz.

2.3 The sound channel

Existing links use a 7.5 MHz f.m. sound subcarrier added to the composite video signal. As a consequence of the reduced bandwidth of the v.s.b. system, the sound subcarrier frequency must be reduced, and 6 MHz was chosen as a convenient frequency. Intermodulation products, principally those at $f_s - f_c$ and $2f_c - f_s$ (where f_s = sound carrier frequency and f_c = colour subcarrier frequency) will of course be increased as a result of the poorer linearity of the v.s.b. system.

3. Experimental arrangement

Practical tests were conducted using the experimental arrangement shown in Fig. 4. The modulator and demodulator were standard commercial units operating with a carrier rest frequency of 70 MHz (the intermediate frequency used in most link equipment); the filters were therefore designed for use at 70 MHz.

The demodulator unit had limiter stages at i.f., but an extra limiter was constructed for use immediately before the demodulator. Limiting (and thus performance) were found to be much better with this extra limiter included.

Bandpass filters for use at 70 MHz were constructed as separate high-pass and low-pass sections for instrumental convenience. An i.f. group-delay equaliser was also constructed for use with the v.s.b. filter; it enabled the group-delay variation with frequency introduced by this filter to be reduced by about 30%. The amplitude and group-delay characteristics of the narrow-band filter (with and without the group-delay equaliser) are shown in Fig. 5. It will be seen, with reference to the photograph of the complete f.m. spectrum in Fig. 1, that the narrow-band filter passes the principal spectral components around the carrier rest frequency of 70 MHz, plus the sidebands extending down to 64 MHz, including the important group of sidebands centred on (70 — 4.43) MHz. Sidebands above 72 MHz and below 64 MHz are attenuated. The spectrum obtained after the signal has passed through the narrow-band filter is shown in Fig. 6.

The required video equaliser response was found by measuring the video amplitude/frequency response of the vestigial sideband f.m. link shown in Fig. 7. A simple bridged-T network was designed to fit this curve and video

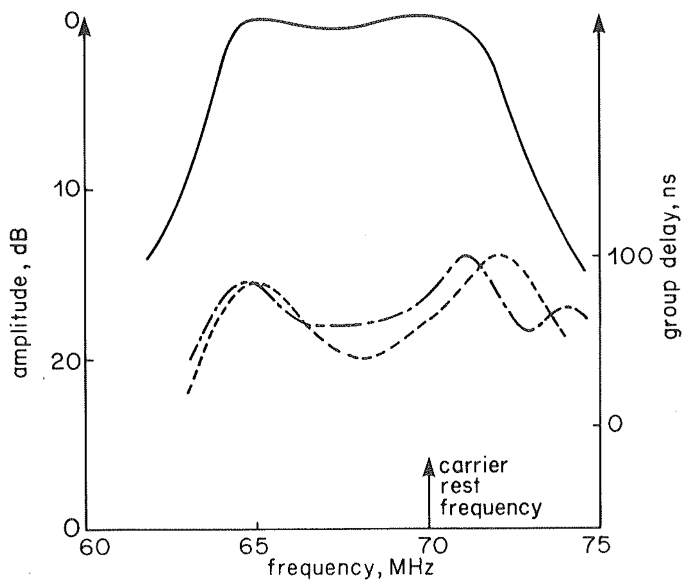


Fig. 5 - Frequency characteristics of the 64 - 72 MHz bandpass filter.

——— Amplitude
- - - - Group delay
—-—-— Group delay with partial correction

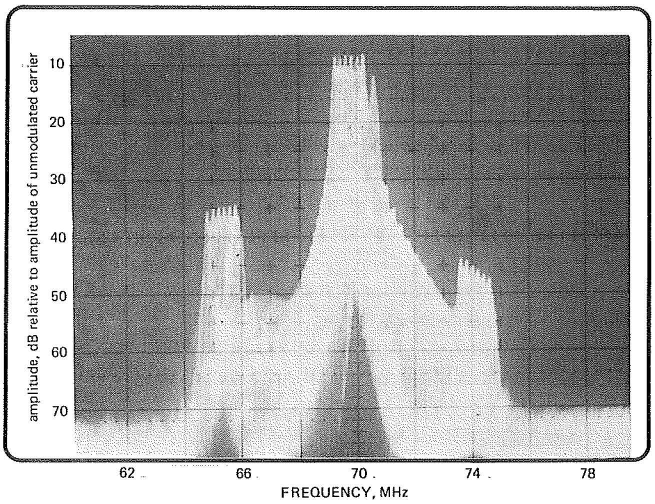


Fig. 6 - Spectrum of signal after v.s.b. filtering

group-delay correction was achieved using a Cintel 'B' group-delay corrector.

Provision was also made for adding a 6 MHz f.m. sound subcarrier to the input video signal before modulation and for retrieving it after the f.m. demodulator.

4. Description of tests

The initial setting-up and testing of the narrow-band f.m. system was performed using two non-linearity television test signals, one having a step ("staircase") waveform with colour subcarrier on each step as shown in Fig. 8, and the other comprising CCIR test waveforms using one line of staircase alternating with three lines of either black level or white level. The performance of the link was measured in terms of the differential gain and differential phase distortion of the colour subcarrier at the video output, for various values of carrier deviation. The effect of partially equalising the group-delay response of the narrow-band filter was also investigated.

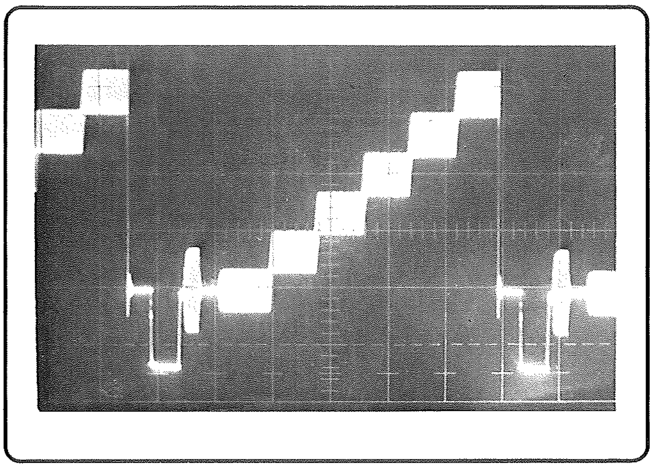


Fig. 8 - Staircase waveform at the output of the waveform generator

In order to evaluate performance under noisy conditions, tests were conducted with noise injected into the system at the input to the i.f. filter. Injection of noise at a high level was adopted in preference to attenuation of the carrier, so as to ensure adequate limiting even at low carrier-to-noise ratios.

The output signal-to-noise ratio was then measured for a number of different carrier-to-noise ratios at the input to the limiter. Carrier-to-noise ratio was determined by using a bolometer power-meter to measure, alternately, carrier power (in the absence of any significant noise) and noise power (in the absence of carrier) at the input to the limiter. Noise measurements were also made using a d.s.b. 16 MHz-bandwidth i.f. filter, keeping the input signal unchanged as for a normal f.m. transmission with 4 MHz peak-to-peak deviation; in this case the carrier-to-noise ratio was determined with reference to 16 MHz bandwidth instead of 8 MHz.

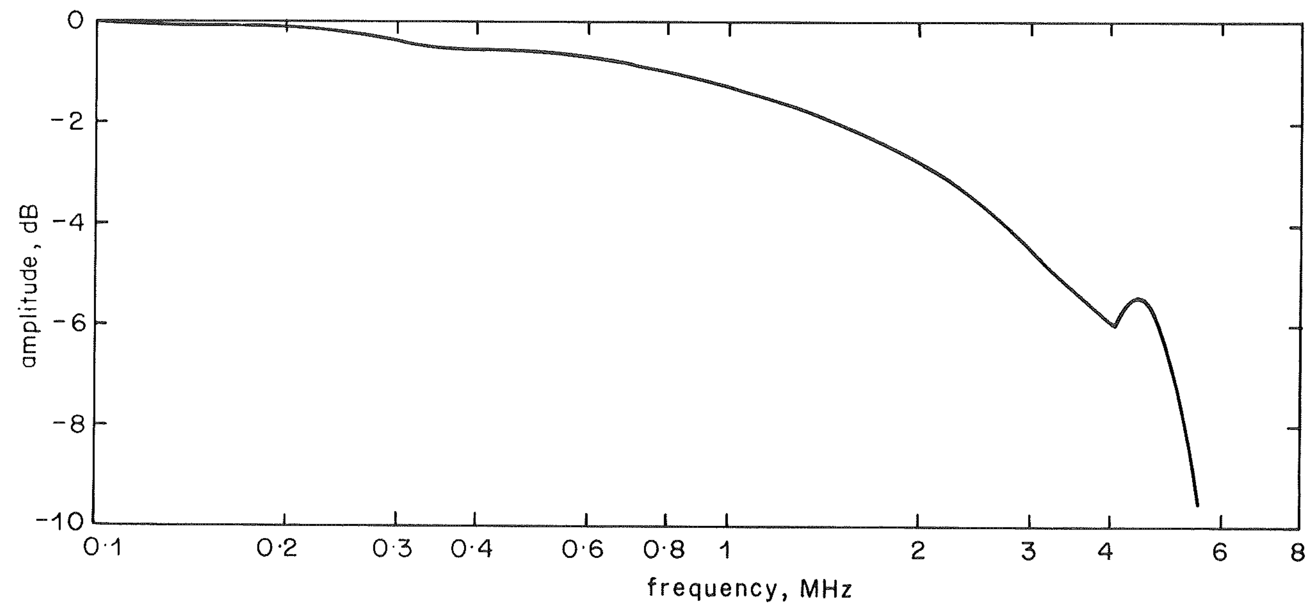
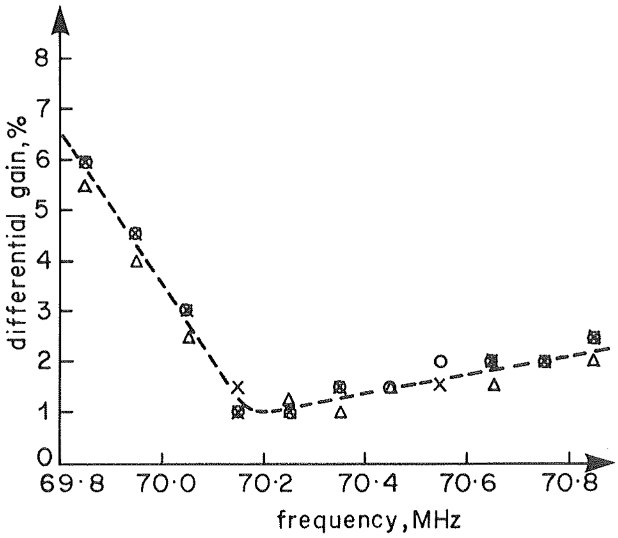
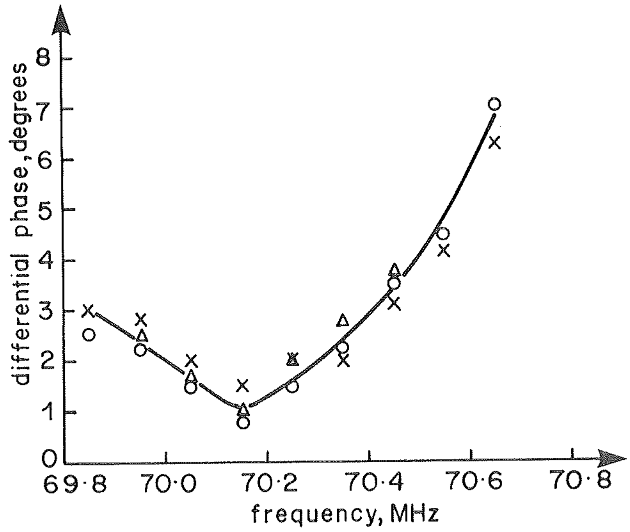


Fig. 7 - Frequency characteristic of the v.s.b. link before equalisation.



(a)



(b)

Fig. 9

(a) Differential gain distortion as a function of the frequency corresponding to black level

(b) Differential phase distortion as a function of the frequency corresponding to black level

o Points obtained for CCIR "bar on" waveform. x Points obtained for CCIR "bar off" waveform. △ Points obtained for staircase waveform.

The behaviour of the system with an added sound subcarrier was also studied. The 6 MHz f.m. sound subcarrier was added to the vision signal and impairments to the picture were assessed subjectively, for various sound subcarrier amplitudes, with both the v.s.b. and the full bandwidth system. The sound channel signal-to-noise ratio was also measured relative to the peak modulation level (± 50 kHz deviation) using the subcarrier amplitude recommended for existing links and a comparision was made between the v.s.b. and full bandwidth systems as above.

Since the video circuits of the commercial f.m. modulator were a.c. - coupled, the effects of clamping the video input waveform could not be investigated directly. The effect of a black-level clamp was simulated by adjusting the carrier rest frequency for each video test waveform, such that black-level always corresponded to a given frequency. Graphs of differential gain and phase distortions as a function of this frequency, are given in Fig. 9.

5. Discussion of results

5.1 Differential gain and phase distortion

Results for the measurements of differential gain and differential phase distortion of the colour subcarrier are given in Table 1. It is evident from these results that group-delay correction of the i.f. filter even to the limited extent employed in these experiments produces a worthwhile reduction in differential phase distortion. It is possible that a more elaborate i.f. group-delay equaliser, giving a greater degree of correction, might be justified, but this was not pursued.

A deviation of 4 MHz peak-to-peak (i.e. 4 MHz peak-to-peak for a 1 volt composite video signal after CCIR pre-emphasis[1]) was adopted for subsequent tests. The worst-case distortions, at this deviation, were 4% for differential gain and 3½° for differential phase, using partial group-delay correction of the i.f. filter.

TABLE 1

Differential gain and phase distortion as a function of deviation

pk-pk Deviation	With Group Delay Corrector			Without Group Delay Corrector		
	CCIR Bar off	CCIR Bar on	Staircase	CCIR Bar off	CCIR Bar on	Staircase
8 MHz	15% 4°	7% 6°	5% 13°	20% 12°	10% 10°	3% 9°
6 MHz	8% 3½°	2% 5°	2% 8°	7% 10°	4% 7°	5% 4°
4 MHz	4% 2°	2% 1½°	— 3½°	3% 5°	1% 3°	2% 2½°
2 MHz	— ½°	1% 1°	— 2°	1% 2½°	1½% 1½°	2% 1°
1 MHz	— —	— ½°	— ½°	— 1°	— 1½°	— ½°

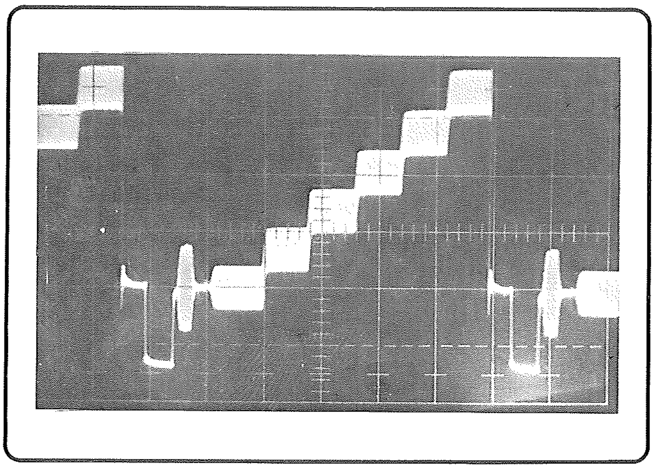


Fig. 10 - Staircase waveform at the output of the v.s.b. link

Since the levels of non-linear distortion are dependent upon the instantaneous level of the input signal, black-level clamping should allow the best differential gain and phase performance to be achieved independently of signal content. This was investigated using the simulated clamping technique mentioned in Section 4 and the results given in Fig. 9 show that clamping the input waveform so that black-level corresponds to 70.15 MHz should give differential gain and phase distortions of 1½% and 1½° respectively for all three test signals.

The non-linearity test waveform obtained at the output of the system is shown in Fig. 10.

5.2 Tests with augmented pulse-and-bar signal

Tests with the augumented pulse-and-bar gave the waveforms shown in Fig. 11 for the 2T pulse, and that in Fig. 12 for the 10T pulse at the output of the f.m. system. The 2T pulse/bar ratio was 96% for the positive pulse and 100% for the negative pulse. Chrominance/luminance gain and delay inequality were reduced to negligible proportions by the video equalisation and phase correction, as can be seen from the 10T pulse shown in Fig. 12.

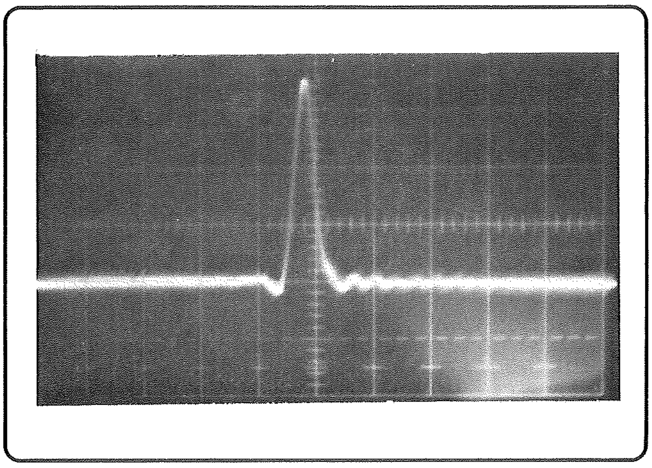


Fig. 11 - Positive 2T pulse response of v.s.b. link.

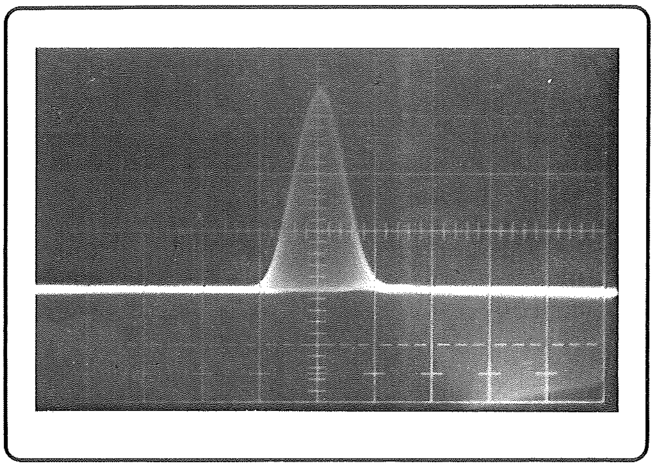


Fig. 12 - 10T pulse response of v.s.b. link.

5.3. Noise performance

The results of the tests with added noise are shown in Fig. 13. Both of the graphs show the threshold characteristic of f.m. systems which occurs at a carrier-to-noise ratio of about 10 dB.

The v.s.b. system appears to have a signal-to-noise ratio about 4 dB lower at its output than the d.s.b. system operating with the same carrier-to-noise ratio at the limiter input. It should be appreciated, however, that, for the same field-strength, the v.s.b. receiver will have a 3 dB higher carrier-to-noise ratio at its limiter input than a d.s.b. receiver because of its lower i.f. bandwidth. Thus the v.s.b. system should give a signal-to-noise ratio only 1 dB less than that of the d.s.b. system when operating at the same field strength.

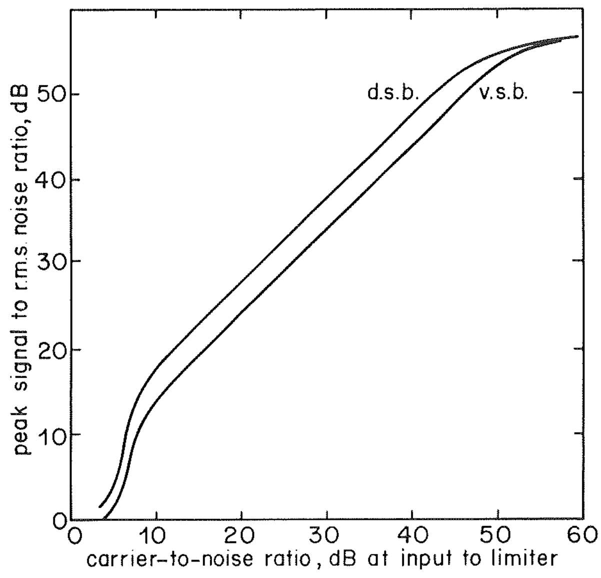


Fig. 13 - Unweighted signal-to-noise ratio as a function of carrier-to-noise ratio.

TABLE 2

Subjective grades for pictures received over both the VSB and the DSB systems with various sound subcarrier levels. (6-point impairment scale)

p-p sound subcarrier level	VSB system	DSB system
+ 2dB	4	4½
− 2dB	3	3
− 8dB	2	1
− 14dB	1	1

* dB relative to 1v video signal (normal d.s.b. value − 14 dB)

5.4 The sound channel

Table 2 shows the impairment grades obtained in a brief subjective test using two observers judging pictures according to a 6-point scale*, when the 6 MHz f.m. sound subcarrier (unmodulated) was added to the video input signal. It can be seen that when the subcarrier was added at the same level as the 7.5 MHz subcarrier used in existing links, (i.e. a peak-to-peak amplitude 14 dB below 1 volt peak-to-peak of video), there was no noticeable impairment to the picture. The v.s.b. system is, of course, more susceptible to intermodulation distortion, illustrated by the subjective grades obtained for higher sound-subcarrier levels.

The sound channel signal-to-noise ratio obtained when using the v.s.b. system, with the sound subcarrier at the same amplitude as for d.s.b., was 8 dB worse than that obtained with the full bandwidth system. This increase in the noise appeared to be caused by interference to the sound channel by the vision signal.

6. Conclusions

An experimental study of a simulated narrow-band f.m. television link has shown that it should be quite feasible to send f.m. television signals in a bandwidth of only 8 MHz, instead of the 16 MHz used at present. Linearity of the narrow-band link is likely to be slightly worse than that of the wideband link. The experimental system in which clamping of the video signal was simulated introduced 1½% differential gain and 1½° differential phase distortion, whereas the wide-band system has very low differential gain (less than 1%) and ½° differential phase distortion. The results obtained suggest, however, that a more thorough correction of the group-delay response of the i.f. filter might improve linearity.

The performance of the narrow-band system under noisy conditions appeared to be almost as good as that of the wideband f.m. system when operating with 4 MHz peak-to-peak deviation (the value normally used in practice).

It was found possible to transmit the normal sound subcarrier in the vision channel, although its frequency had to be lowered to 6 MHz because of the reduced bandwidth of the v.s.b. system. Under these circumstances, the sound channel signal-to-noise ratio was found to be reduced by 8 dB. Moreover, the margin of protection against visible interference to the picture from the sound signal was reduced by about 6 dB.

It seems likely that the principal problem, increasing over the next few years, will be that of interference from u.h.f. television broadcasts into the link; interference to broadcast reception by the link is likely to be less serious. One possibility which could be considered therefore, would be to use a conventional, wide-band f.m. transmitter for the link but to retain the option of using wide-band or v.s.b. narrow-band receiver techniques. A receiver with optional wide or narrow bandwidth i.f. filters, plus the appropriate video equaliser for use with the narrow-band i.f. filters, could then be used in either mode depending on the interference being received from Band V broadcast transmitters. Other reports in this series give further consideration to this possibility.

Nevertheless, the use of a wide-band transmission would depend on there being no likelihood of the link transmitter causing interference to broadcast reception. The present link transmitters give an output power in the region of 2 watts which seems unlikely to create a very extensive interference field. Should future developments lead to links being provided with greater transmitter powers, however, it is possible that the link transmitter bandwidth will have to be restricted. The necessary filter for this would have to be placed after any non-linear amplifier and this might mean that a different filter would be needed for each u.h.f. channel; there could therefore be some inconvenience, together with a significant increase in cost, if this option were to be provided.

7. References

1. CCIR: Recommendations 405-1 XIIth Plenary Assembly (New Delhi, 1970). Vol. VI, Part 1, p. 148, Curve B (625-lines).
2. GILCHRIST, N.H.C., 1977. Narrow-band f.m. system for television links: test of performance under conditions of multipath propagation. BBC Research Department Report No. 1978/22.
3. GILCHRIST, N.H.C, LYNER, A.G, 1977. Narrow-band f.m. system for television links: interference between f.m. and a.m. television signals. BBC Research Department Report No. 1978/21.
4. LAVEN, P.A., CORNELL, D.R., 1977. Narrow-band f.m. system for television links. BBC Research Department Report in course of preparation.

* The 6-point impairment scale used was that given in CCIR Report 405-1 (New Delhi, 1970) and is as follows: 1. Imperceptible; 2. Just perceptible; 3. Definitely perceptible but not disturbing; 4. Somewhat objectionable; 5. Definitely objectionable; 6. Unusable.

Appendix

Using the rotating vector approach of Fig. 14, it can be shown that the effect of shaping the f.m. spectrum is to reduce the amplitude of the high-frequency components of the demodulated waveform. Low-frequency components of the modulating waveform are transmitted and received as double-sideband signals and are therefore unaltered. The higher-frequency components, however, are converted into single-sideband signals by the spectrum shaping filter.

For high modulating-frequencies, the f.m. signal can be represented approximately by a vector rotating at the carrier rest frequency (ω_o) and two sideband vectors rotating at ($\omega_o \pm \omega_m$) as shown in Fig. 4(a). The higher-order sidebands are of relatively small amplitude, and have been omitted for simplicity. The phase deviation (ϕ) is proportional to the level of the modulating signal. The effect of shaping the spectrum of a signal carrying the higher modulating-frequencies using the filter characteristic shown in Fig. 3 is to remove the vector at ($\omega_o + \omega_m$), thereby reducing the phase deviation and, since the resultant R is no longer of constant length, to introduce some amplitude modulating (see Fig. 14(b)). Non-linear distortion of the phase deviation characteristic is also introduced. Subsequent limiting removes the amplitude modulation, effectively by redistributing the sideband power in such a way as to give a constant amplitude (see Fig. 14(c)), but does not alter the phase deviation (ϕ') of the v.s.b. signal. The new sidebands are similar, but not identical, to the sidebands present in the original double-sideband f.m. signal, and are at a lower amplitude.

Thus the change from d.s.b. to v.s.b. operation with increasing modulation frequency gives the sloping amplitude characteristic of the unequalised v.s.b. link shown in Fig. 7.

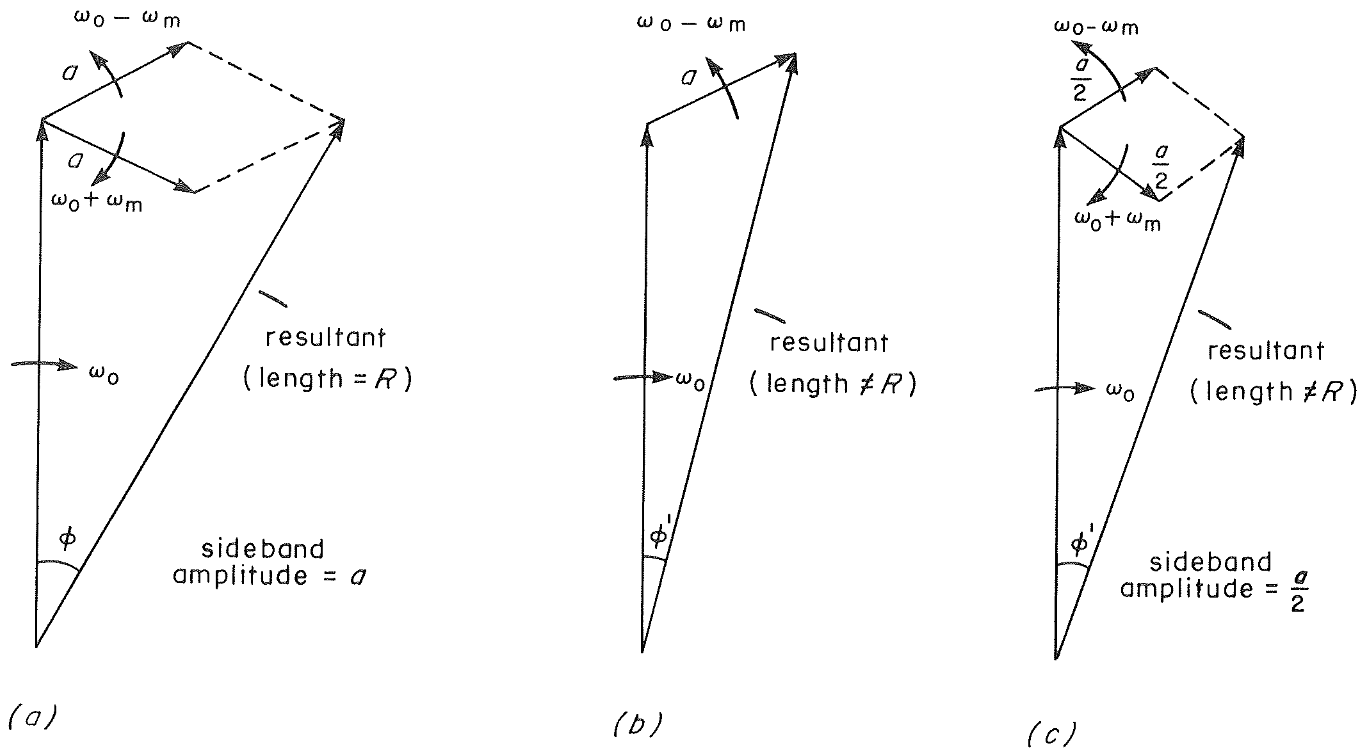


Fig. 14
(a) Vector diagram for f.m. with a small modulation index.
(b) Vector diagram of an f.m. signal with one sideband removed.
(c) Vector diagram of the single sideband signal after limiting.

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